

A Micro Vertex System in a EIC Detector based on Monolithic Active Pixel Sensors

Benedetto Di Ruzza (BNL)



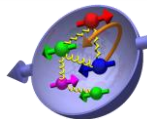
2013 Fall Meeting of the APS Division of Nuclear Physics

October 23-26, 2013; Newport News, Virginia

Benedetto Di Ruzza DNP-2013 Meeting

Most Compelling SCIENCE Questions at an EIC

spin physics



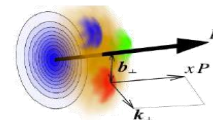
what is the polarization of gluons at small x where they are most abundant



what is the flavor decomposition of the polarized sea depending on x

determine quark and gluon Contributions to the proton spin at last

imaging



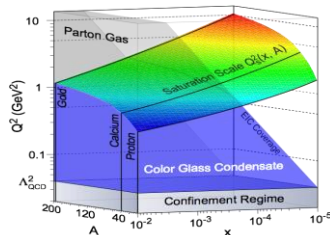
what is the spatial distribution of quarks and gluons in nucleons/nuclei



understand deep aspects of gauge theories revealed by k_T dep. distribution

possible window to orbital angular momentum

physics of strong color fields



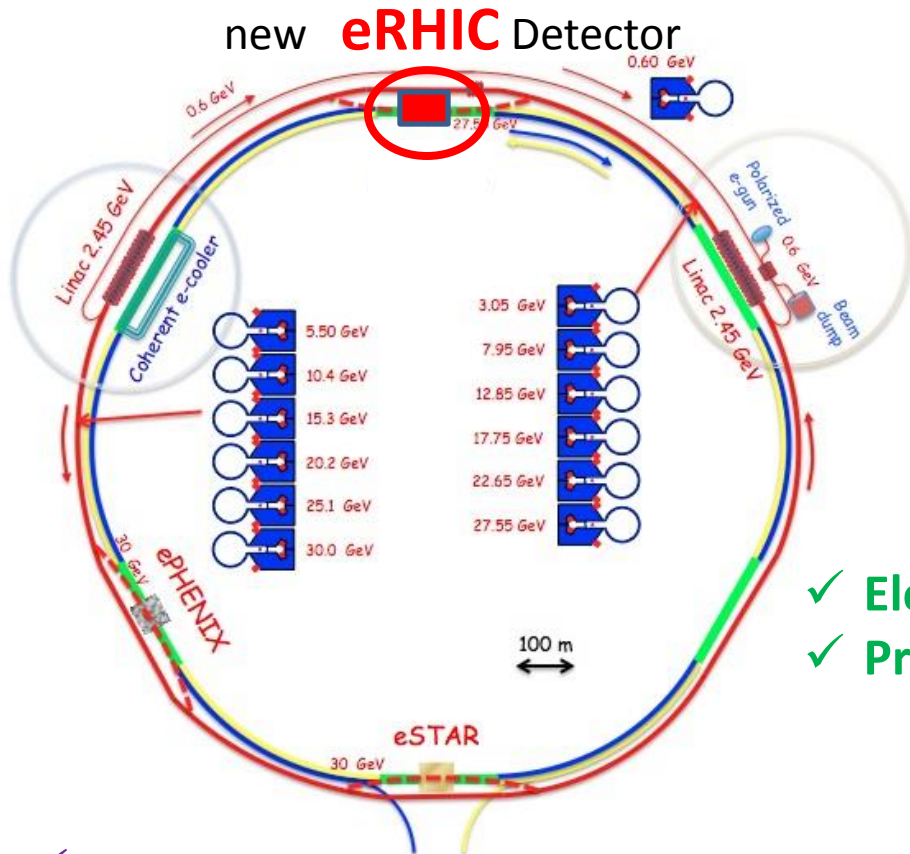
understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
how do hard probes in eA interact with the medium



quantitatively probe the universality of strong color fields in AA, pA, and eA

For details see in this meeting: **Session KE: Mini-Symposium on the Physics Program at EIC**
<http://meetings.aps.org/Meeting/DNP13/Session/KE>

eRHIC: an EIC collider at BNL



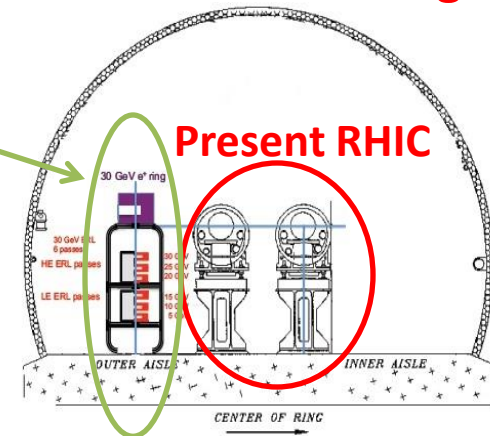
Collisions:

- ✓ Polarized electrons : 10, 20, (30?) GeV
- ✓ Polarized protons : 75, 250 GeV
- ✓ Ions. 50, 100 GeV/u

Keypoints:

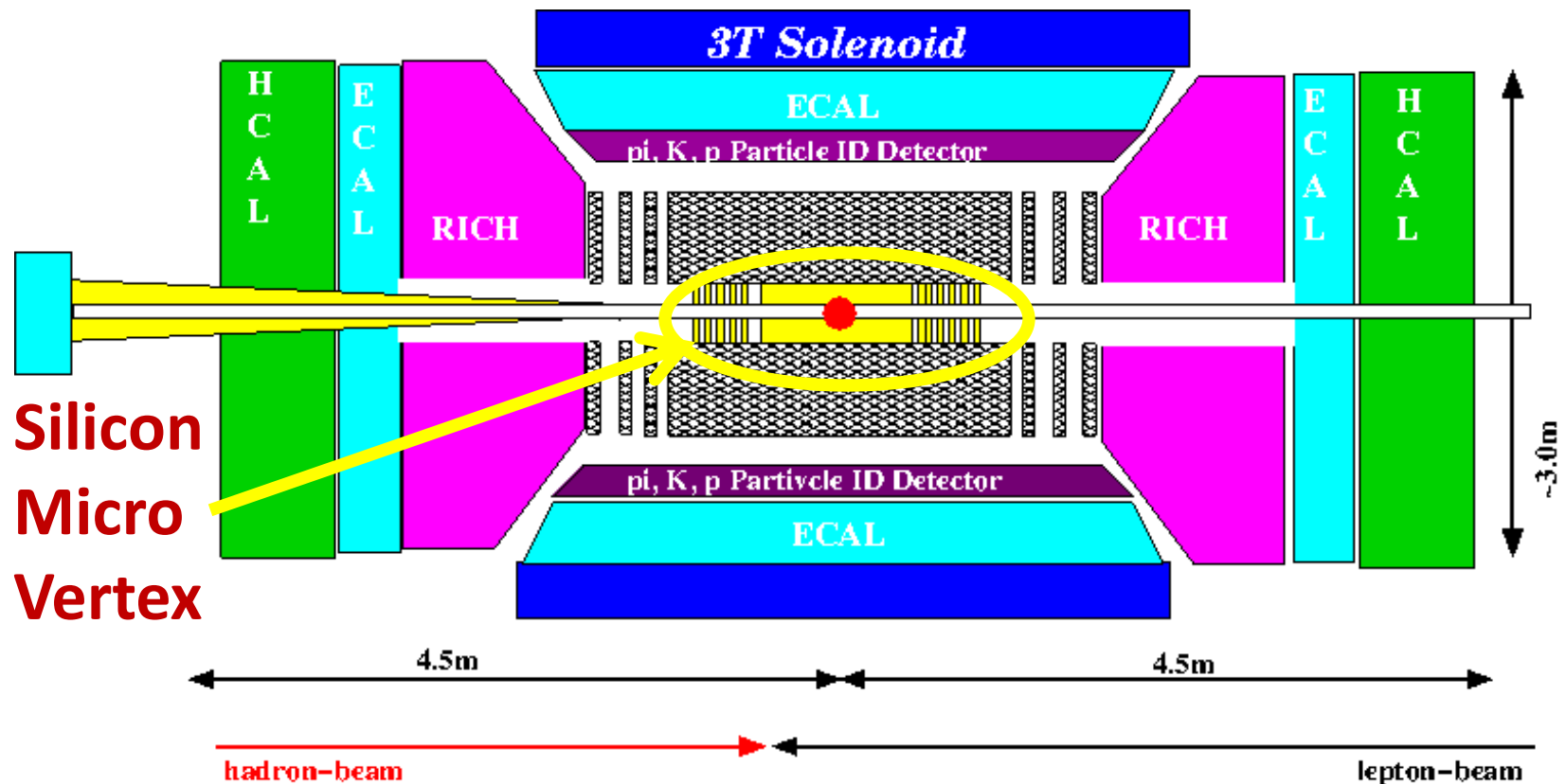
- ✓ Electron beam: **NEW** High Energy ERL.
- ✓ Proton beam: **NEW** coherent electron cooling.

New e-ring



- ✓ No other tunnel required: electron beam line will be added in the present RHIC tunnel.
- ✓ Up to 3 experimental locations available.

Overview of the New eRHIC Detector



Goals:

- high acceptance $-5 < \eta < 5$ central detector
- good PID (π, K, p and lepton) and vertex resolution ($< 5\mu\text{m}$)
- tracking and calorimeter coverage the same \rightarrow good momentum resolution, lepton PID
- low material density \rightarrow minimal multiple scattering and brems-strahlung
- very forward electron and proton/neutron detection \rightarrow maybe dipole spectrometers

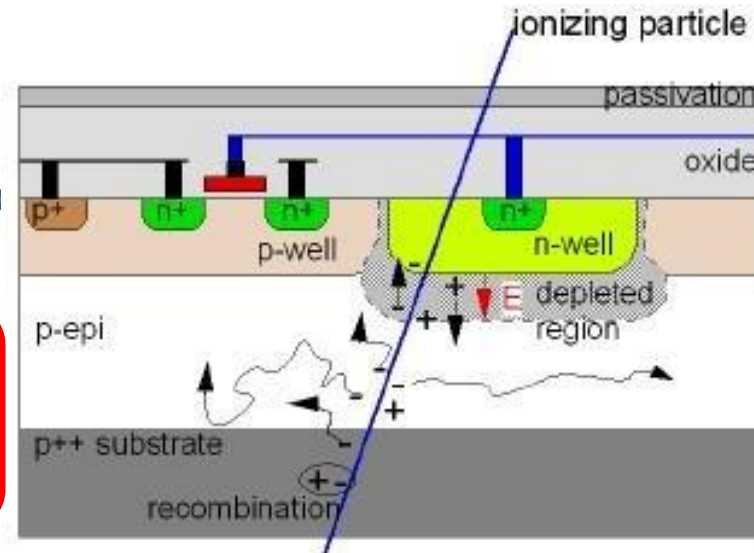
A Silicon Micro Vertex for eRHIC

Vertex system based on
Monolithic Active Pixel Silicon
Sensor (MAPS)

MAPS type candidate: MIMOSA

Tests ongoing at BNL:

MAPS Mimosa 26 (digital output) designed in the
Institut Pluridisciplinaire Hubert Curien, Strasbourg (FR).




Keypoints:

- ✓ All the sensor is produced using a **standard CMOS technology**.
- ✓ **No Bump bonding** required.
- ✓ Works at **room temperature**: low cooling material budget.
- ✓ **Low bias voltage required**: electrons are collected for thermal diffusion.
- ✓ **High segmentation**: pixel dimension $\sim 20 \times 20 \mu\text{m}^2$

A Silicon Micro Vertex Detector for eRHIC

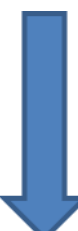
MIMOSA 26: used in our test

- 
- 0.35μm CMOS process (AMS: up to 4 metal layers), with high-resistivity epitaxial layer
 - Column architecture with in-pixel amplification (CDS) and end-of-column discrimination, followed by zero suppression → binary charge encoding
 - Read-out in rolling shutter mode
 - Active area: 1152 columns of 576 pixels (21.2×10.6 mm²)
 - Pitch: 18.4 μm ~ 0.7 million pixels
 - 2 outputs at 80 MHz (Data1 and Data2)
 - Power consumption ~250 mW/cm² (~520 μW/col)
 - Readout frame time 112 μs

MIMOSA 28 (Ultimate): used in the STAR PXL upgrade

- 
- Same 0.35μm CMOS process, different design of the array, keep all the other features

MIMOSA32 and 34: prototype under studies

- 
- 0.18μm CMOS process (TowerJazz: up to 6 metal layers), with high-resistivity thick epitaxial layer (18-40 μm)
 - All the features of the 26 and 28
 - Studies ongoing to reduce the readout time to 30/40 μs
 - Best candidate for a EIC detector for radiation hardness and thickness of sensors
 - best candidate for silicon MAPS wheel because of the two extra metal layers
 - Also approved for ITS ALICE upgrade, candidate for CBM and ILD detectors

For the cooling system we are exploring the possibility of a micro channeling cooling system

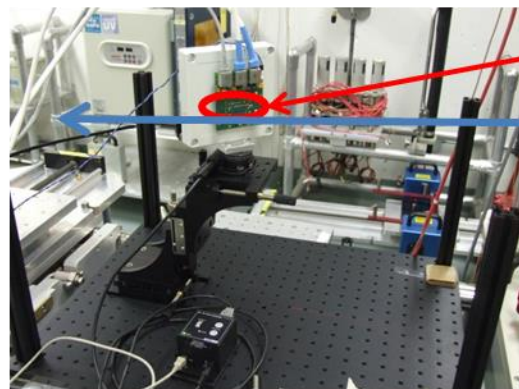
The BNL NASA Space Radiation Laboratory

In this Lab there is one of the few beam-lines able to deliver many different type of ions. This beam line is mainly devoted to irradiation studies of electronic devices and biological tissue. **We decided to make a test here in order to compare the clustering in the sensor using different type of Ions**

Beam-line characteristics:

- 1) beams of protons/heavy ions extracted from the BNL Booster accelerator
- 2) Available ions beams: iron-56, gold-97, silicon-28, protons, titanium, carbon
- 3) Beam spot tunable up to $10 \times 10 \text{ cm}^2$ with spill duration of 0.2 s every 4s
- 4) Number of particle tunable until few/spill

NSRL Test beam set-up



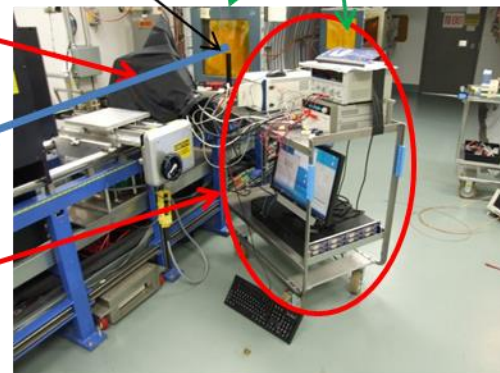
Silicon Sensor:
 $2 \times 1 \text{ cm}^2$

Beam Direction

Mimosa movable
D.A.Q. System

Scintillator
(trigger)

NSRL beam monitors



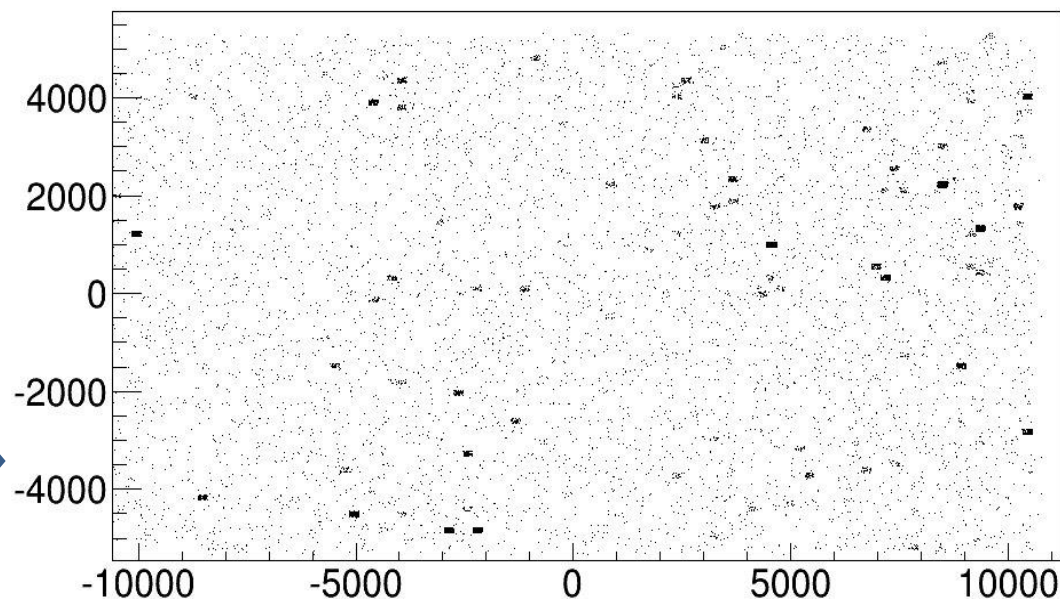
Irradiation with protons beam

Pixel multiplicity in hits of plane 1 - REF

hhitpixl1	
Entries	11058
Mean	1.818
RMS	1.759

- Proton Energy: 1GeV
- DAQ Trigger: Fixed 4kHz (no spill synchronization)
- Beam intensity :5000 particle/spill cm²

Hit map of plane 1 - REF

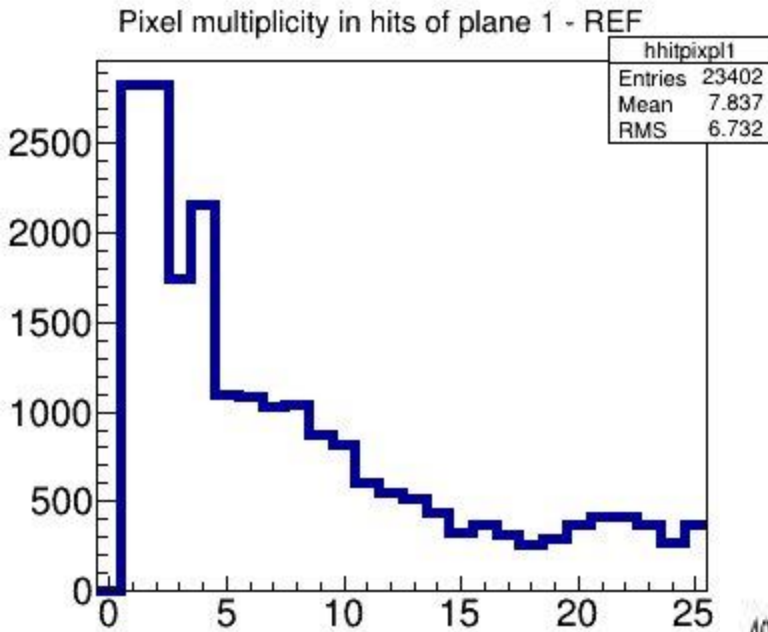


Clustering in 50000 frames
(Frame= read-out of the whole array)

Hits distribution in 50000 frames
(X,Y axis= um of one pixels array)
High noise due to lots of empty frames
(no synchronization)



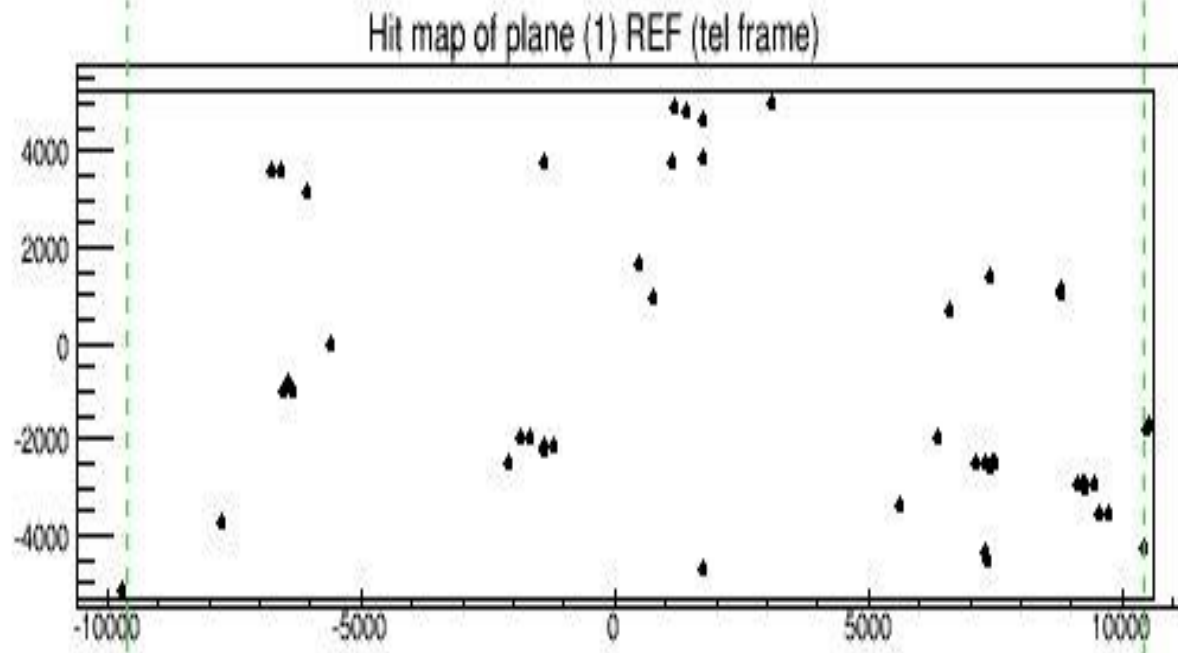
Irradiation with Silicon ions



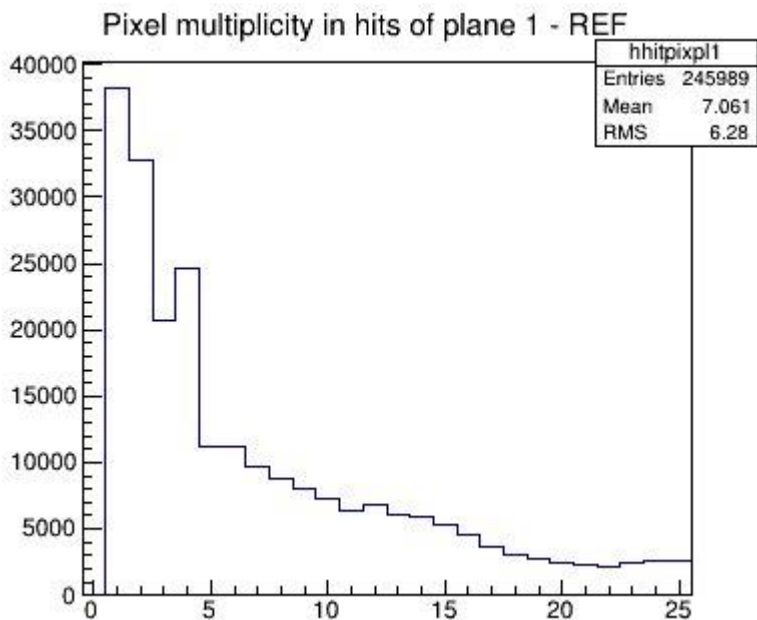
Clustering in 700 frames

Occupancy in only one frame

- Silicon Ion Energy: 600MeV/U
- Sensor orientation: 45 degree
- DAQ Trigger: Fixed 4kHz (with spill synchronization)
- Beam intensity : 60000 particle/spill cm²

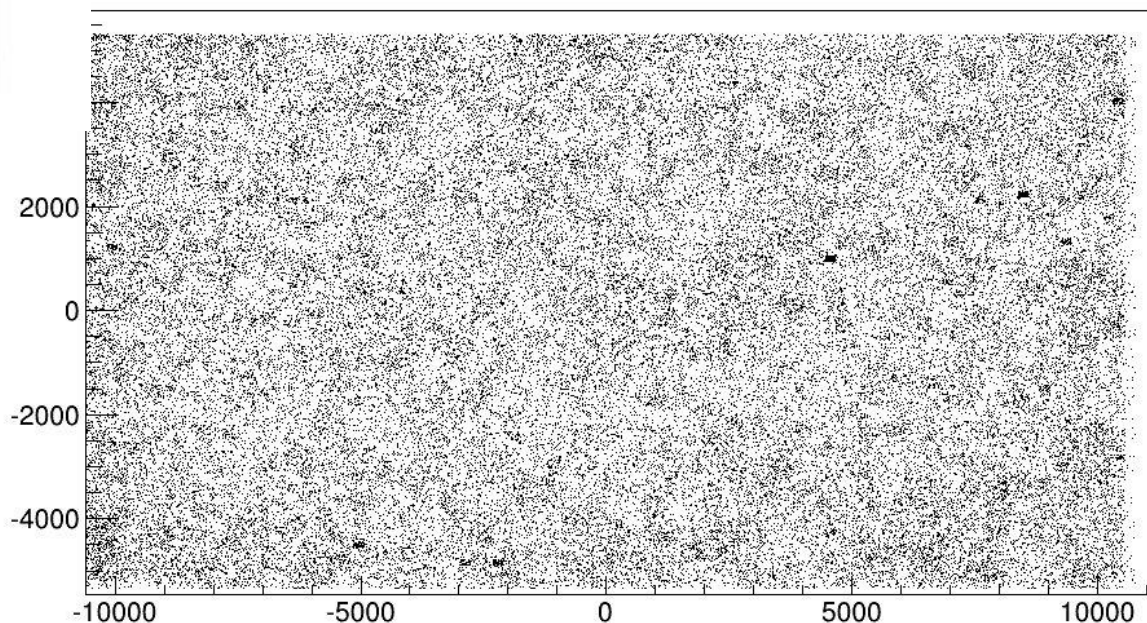


Irradiation with Iron beam



- Iron Ion Energy: 1GeV/U
- Sensor orientation: 45 degree
- DAQ Trigger: Fixed 4kHz
(with spill synchronization)
- Beam intensity : 7000 particle/spill cm²
Hit map of plane 1 - REF

Clustering in 50000 frames



Clustering in 10000 frames

Conclusions

The present status of the MAPS technology confirms this silicon sensor type as the

- best candidate for the inner tracking of a EIC/eRHIC detector.
- The new 0.18 CMOS technology and the new design reduce a lot the readout time of the array.
- The new 6 metal layer technology and the radiation hardness is the key for the construction of the wheels with MAPS technology, something completely new.
- These wheels, with low mass will allow to high resolution ideal to get a good Dp/p in the forward direction.
- In BNL we have unique beamline to develop these kind of prototypes and we are developing the know-how to do this..
- In this first test with maps under ions beam we realized that the noise level in the spare chip used was too high for good measurements, but we define the procedure to do this type of test.

PLANS:

In the future we want repeat these test with the new prototype MIMOSA32 and 34 with digital and analog readout.

Thanks for your attention !

This work was possible only thanks the efforts , the collaboration and help of all the BNL NSLR staff members, a special thanks to Michael Sivertz, Adam Rusek, Chiara La Tessa and Marta Rovituso

This work was supported with BNL LDRD project #11-036

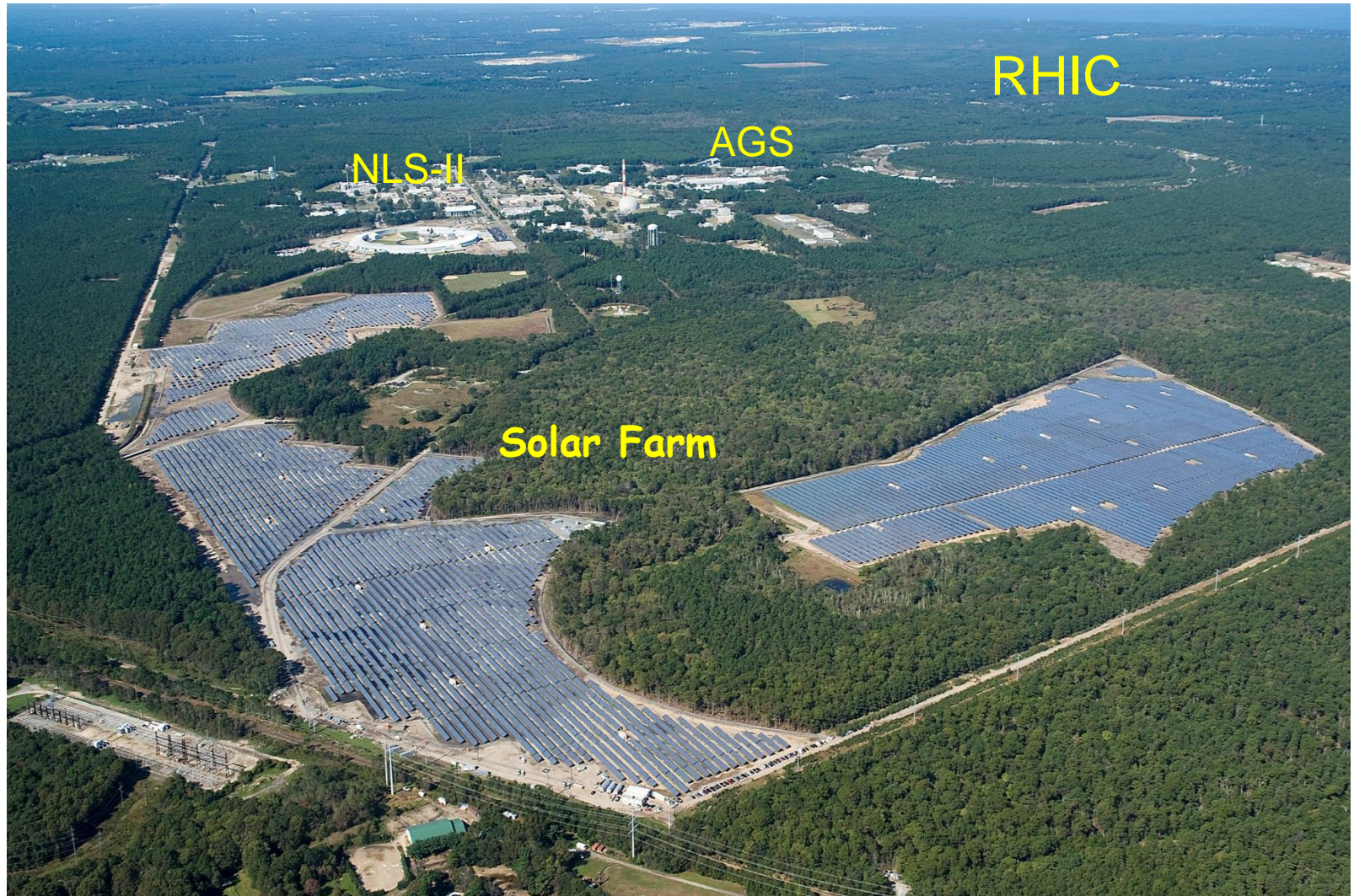
Links to EIC related information

- **eRHIC BNL home page**
<https://wiki.bnl.gov/eic>
- **eRHIC BNL Collider Accelerator Department**
<http://www.bnl.gov/cad/eRhic/>
- **EIC White Paper**
<http://arxiv.org/abs/1212.1701>
- **NASA Space Radiation Laboratory at Brookhaven**
http://www.bnl.gov/medical/nasa/nsrl_description.asp
- **EIC Montecarlo page**
<https://wiki.bnl.gov/eic/index.php/Simulations>
- **Call for EIC R&D proposals**
https://wiki.bnl.gov/conferences/index.php/EIC_R%25D
- **EIC R&D Simulation workshop (BNL October 8TH -9TH 2012)**
https://wiki.bnl.gov/conferences/index.php/EIC_RD_Simulation/Agenda
- **Gluons and quark sea at high energies:**

Report on a ten week program that took place at the Institute for Nuclear Theory (Seattle, Fall 2010) <http://arxiv.org/abs/1108.1713>

For the latest results on the MIMOSA32/34 see for example :
Serhiy Senyukov (IPHC-CNRS Strasbourg) on behalf of the PICSEL group,
(IPRD13) 7 - 10 October 2013 Siena, Italy
<http://www.bo.infn.it/sminiato/sm13/abstract/S2/s-senyukov.pdf>

Brookhaven National Laboratory



BACK-UP Slides

MIMOSA-26: Functionality Implementation

CMOS 0.35 μm OPTO technology
Chip size : 13.7 x 21.5 mm²

- Testability: several test points implemented all along readout path
 - Pixels out (analogue)
 - Discriminators
 - Zero suppression
 - Data transmission

- Row sequencer
- Width: ~350 μm

- 1152 column-level discriminators
 - offset compensated high gain preamplifier followed by latch

- Zero suppression logic

- Reference Voltages Buffering for 1152 discriminators

- I/O Pads
 - Power supply Pads
 - Circuit control Pads
 - LVDS Tx & Rx

- Pixel array: 576 x 1152, pitch: 18.4 μm
- Active area: ~10.6 x 21.2 mm²
- In each pixel:
 - Amplification
 - CDS (Correlated Double Sampling)

- Current Ref.
- Bias DACs

- Readout controller
- JTAG controller

- Memory management
- Memory IP blocks

- PLL, 8b/10b optional

Overview of the New Detector

- **Si-Vertex**
 - MAPS technology from IPHC ala STAR, CBM, Alice, ...)
 - Barrel:
4 double sided layers @ 3. 5.5 8. 15. cm 10 sectors in Φ
 - Forward Disks:
4 single sided disks spaced in z starting from 20 cm, dual sided readout or GEM ?
- **Barrel Tracking**
 - Preferred technology TPC (alternative GEM-Barrel tracker Mass?)
 - Low mass, PID e/h via dE/dx
- **Forward tracking**
 - GEM-Trackers
- **Forward/Backward RICH-Detectors**
 - Momenta to be covered: 0.5-80 GeV for $1 < |\eta| < 4(5)$
 - Technology:
 - Dual Radiator (HERMES, LHCb) Aerogel+Gas (C_4F_{10} or C_4F_8O)
 - Photodetector: low sensitivity to magnetic field

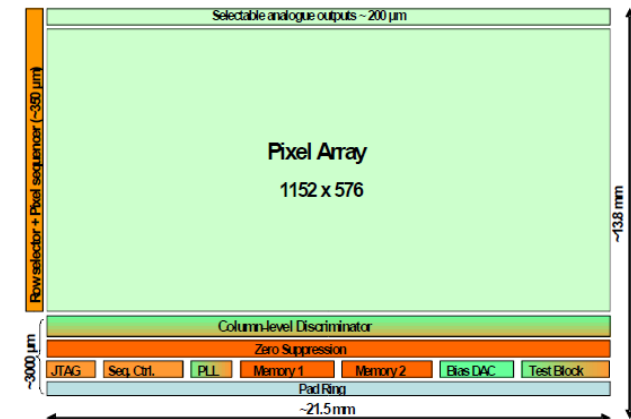
Overview of the New Detector

- **Barrel PID-Detectors**
 - Momenta to be covered 0.5-10 GeV for $-1 < y < 1$
 - Technology:
 - Aerogel Proximity focusing RICH
 - DIRC
- **ECal:**
 - Backward/Barrel:
 - PbW-crystal calorimeter → great resolution, small Molière radius → electron-ID: e/p, measure lepton via Ecal, important for DVCS
 - Forward:
 - Less demanding: sampling calorimeter
- **Preshower**
 - Si-W technology as proposed for PHENIX MPCEX
- **Hcal/Muons-Detectors**
 - Not obvious they are really needed
- **Luminosity monitor, electron and hadron polarimeters**

Silicon Vertex

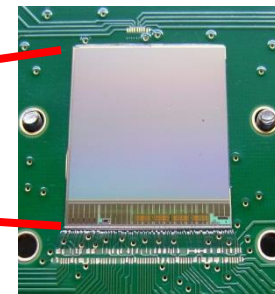
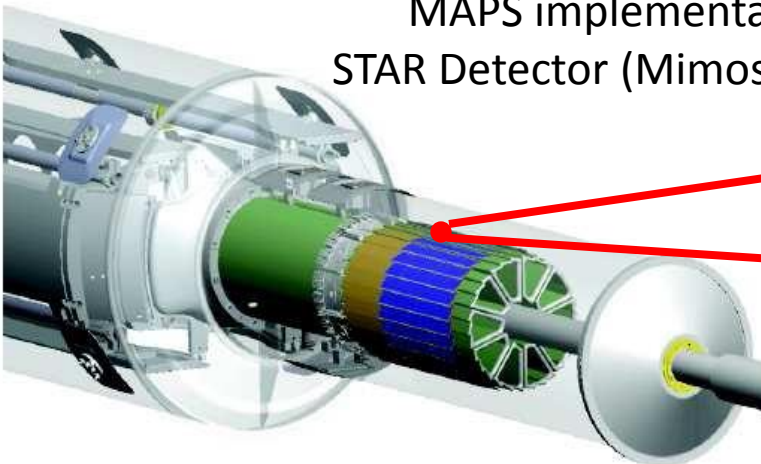
Mimosa 26 :

- ✓ Matrix of 663 552 pixels: 576 lines x 1152 col.
- ✓ 13.7 mm X 21.5 mm Matrix Surface
- ✓ Pitch= 18 μm
- ✓ Sensitive volume thickness 15 μm
- ✓ Digital data stream after zero suppression



See for details: <http://www.iphc.cnrs.fr/List-of-MIMOSA-chips.html>

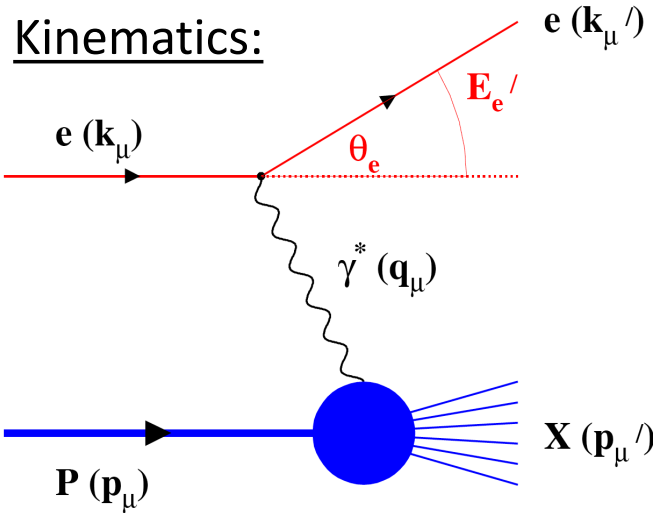
MAPS implementation in the STAR Detector (Mimosa 28 Ultimate)



[http://indico.scc.kit.edu/indico/getFile.py/
access?contribId=6&resId=0&materialId=slides&confId=27](http://indico.scc.kit.edu/indico/getFile.py/access?contribId=6&resId=0&materialId=slides&confId=27)

How to see the gluons: Deep Inelastic Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2 \quad \text{Measure of resolution power}$$

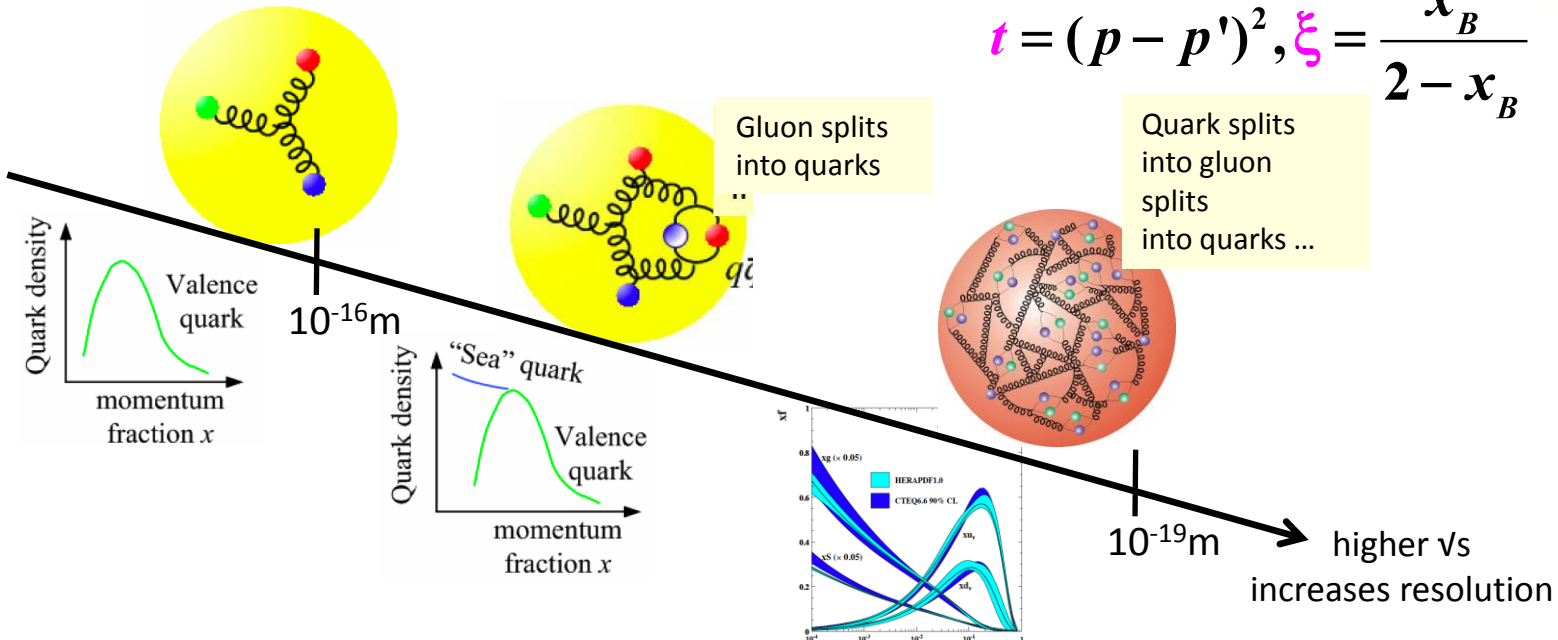
$$Q^2 = 2E_e E'_e (1 - \cos \Theta_e)$$

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e} \cos^2 \left(\frac{\Theta'_e}{2} \right) \quad \text{Measure of inelasticity}$$

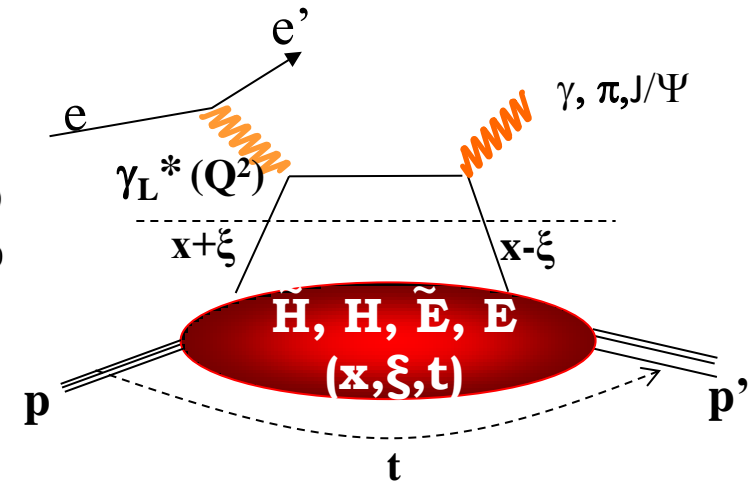
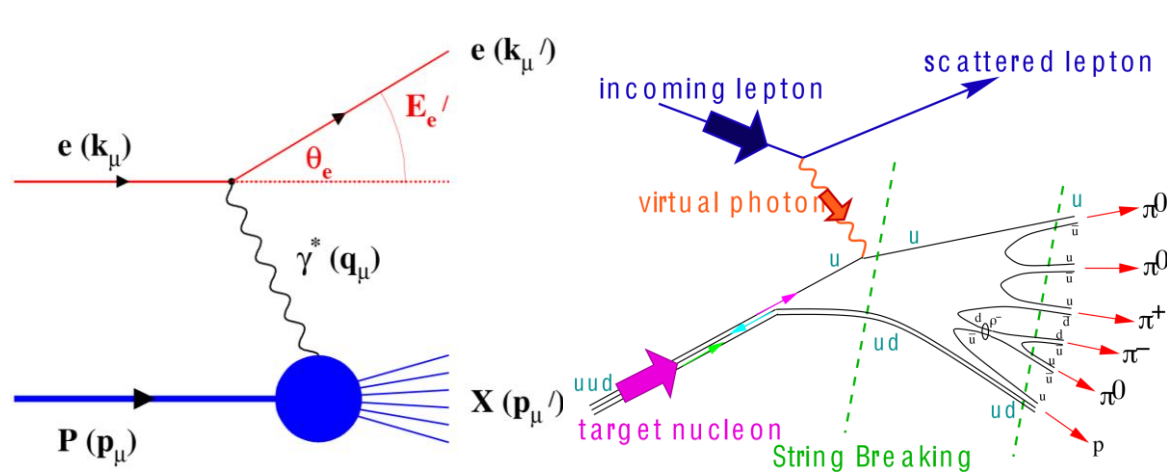
$$\text{Hadron : } z = \frac{E_h}{\nu}; \quad x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy} \quad \text{Measure of momentum fraction of struck quark}$$

p_i^h : with respect to γ^*

$$t = (p - p')^2, \quad \xi = \frac{x_B}{2 - x_B}$$



What needs to be covered



Inclusive Reactions:

- ☐ Momentum/energy and angular resolution of e' critical
- ☐ Very good electron id
- ☐ Moderate luminosity $>10^{32} \text{ cm}^{-1} \text{ s}^{-1}$
- ☐ Need low $x \sim 10^{-4} \rightarrow$ high \sqrt{s} (Saturation and spin physics)

Semi-inclusive Reactions:

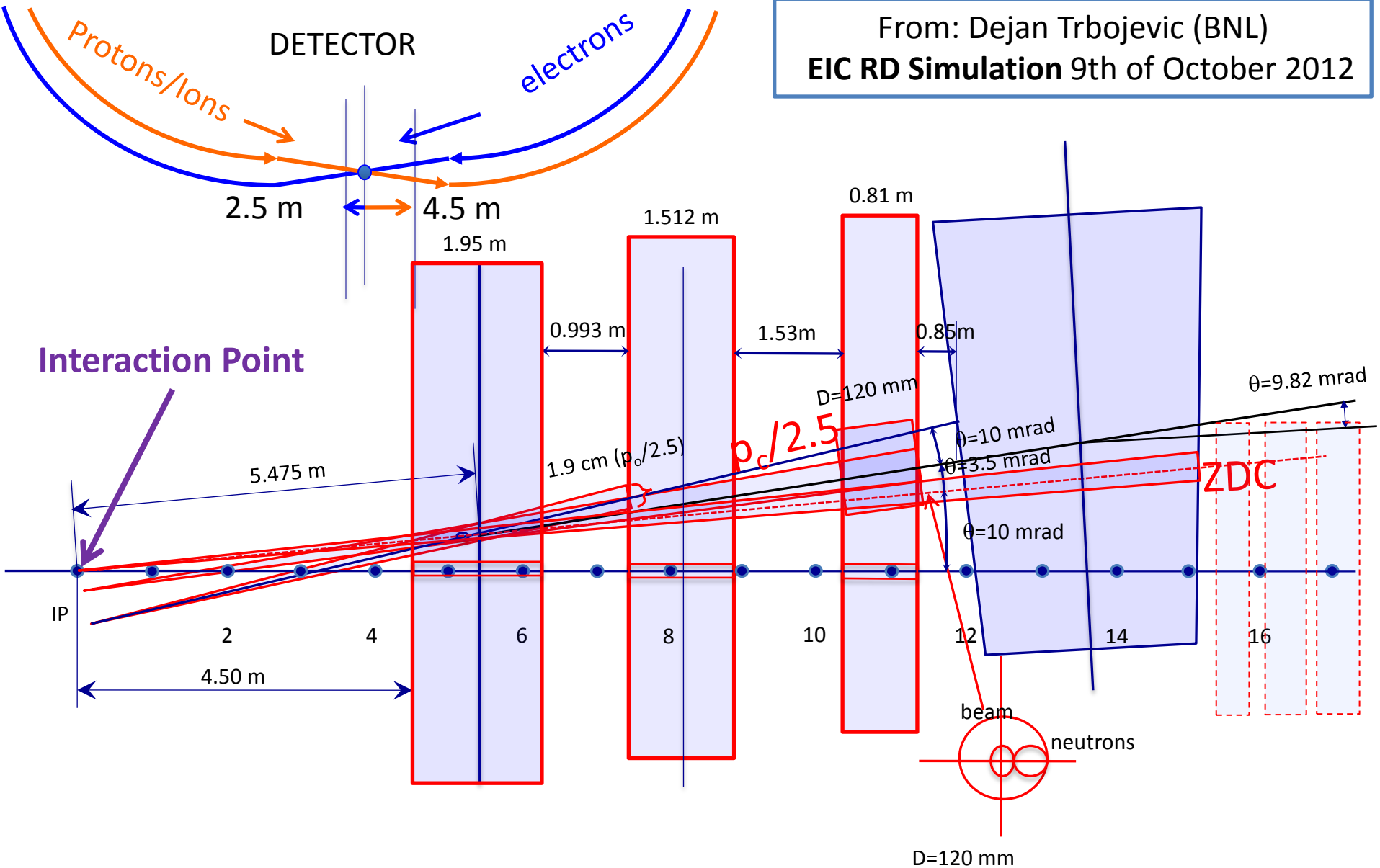
- ☐ Excellent particle ID: π, K, p separation over a wide range in η
- ☐ full Φ -coverage around γ^*
- ☐ Excellent vertex resolution \rightarrow Charm, bottom identification
- ☐ high luminosity $>10^{33} \text{ cm}^{-1} \text{ s}^{-1}$ (5d binning (x, Q^2, z, p_t, Φ))
- ☐ Need low $x \sim 10^{-4} \rightarrow$ high \sqrt{s}

Exclusive Reactions:

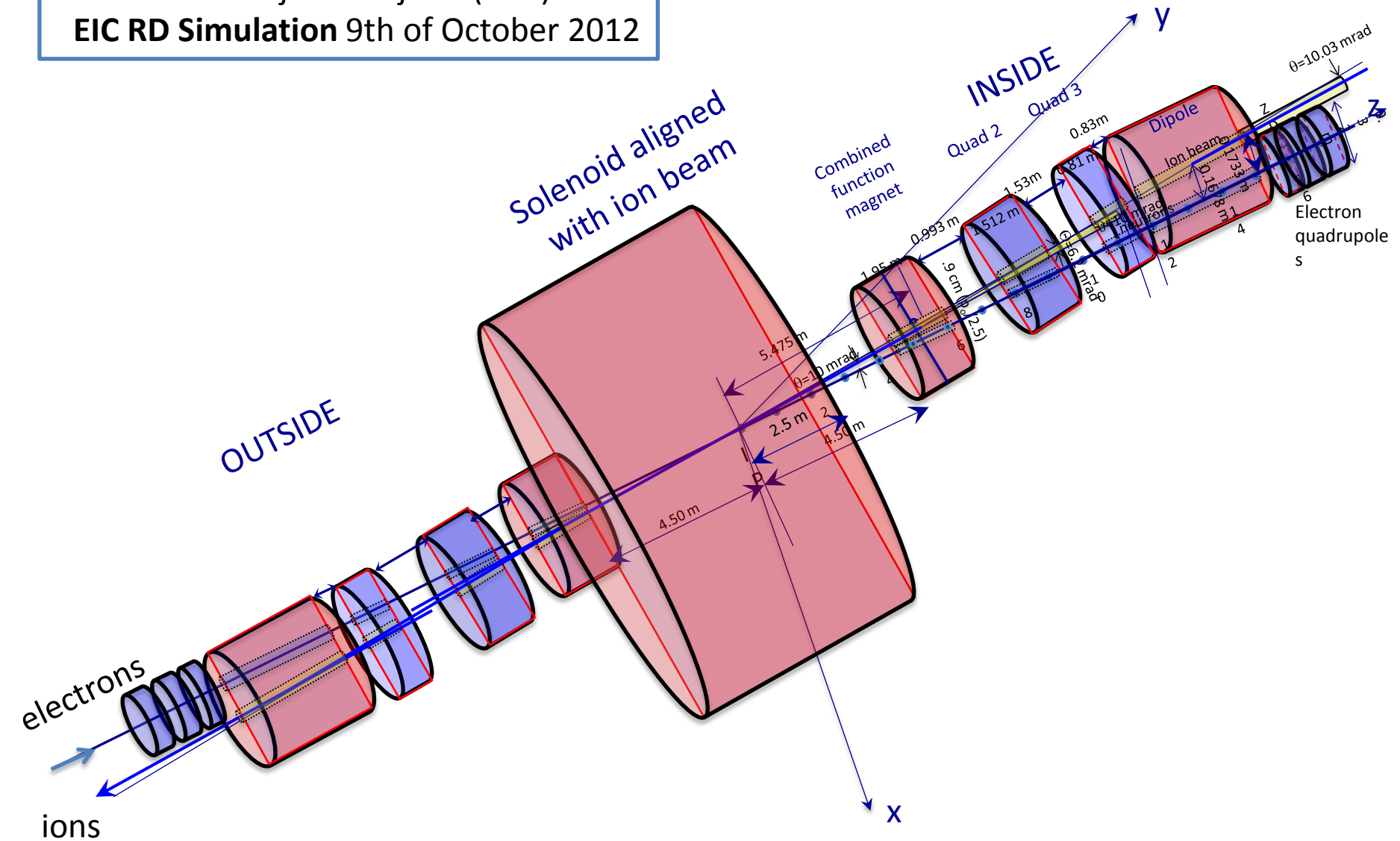
- ☐ Exclusivity \rightarrow high rapidity coverage \rightarrow rapidity gap events
- ☐ high resolution in $t \rightarrow$ Roman pots
- ☐ high luminosity $>10^{33} \text{ cm}^{-1} \text{ s}^{-1}$ (4d binning (x, Q^2, t, Φ))

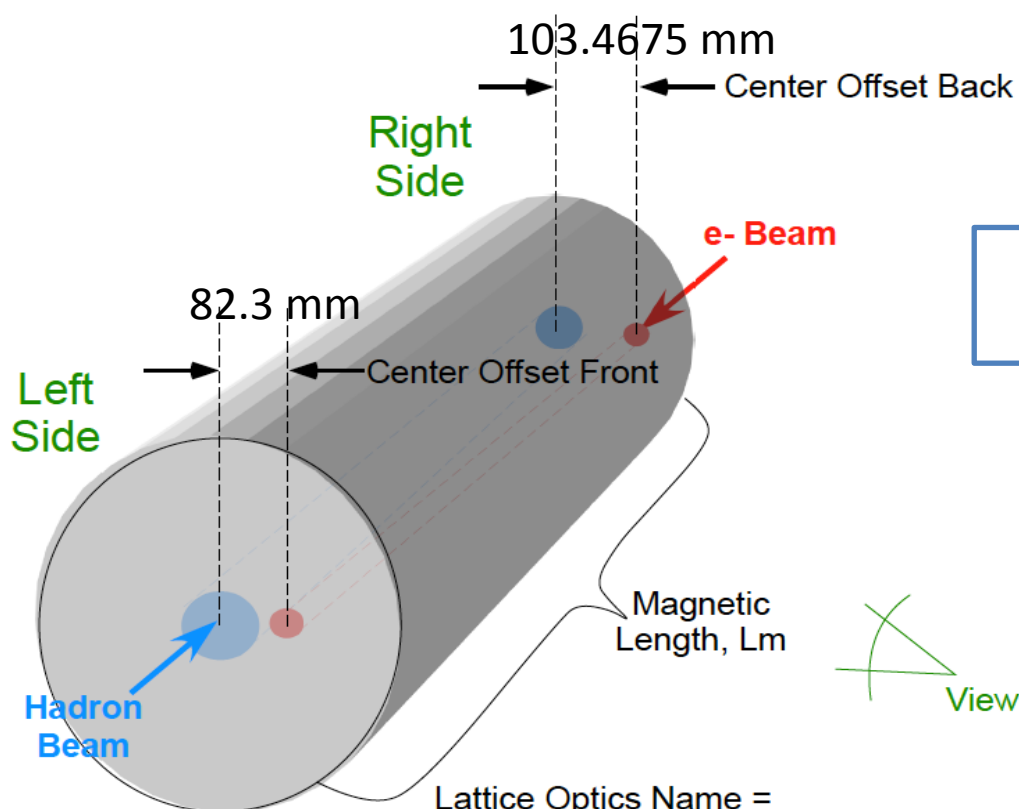
IP configuration for eRHIC

From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012



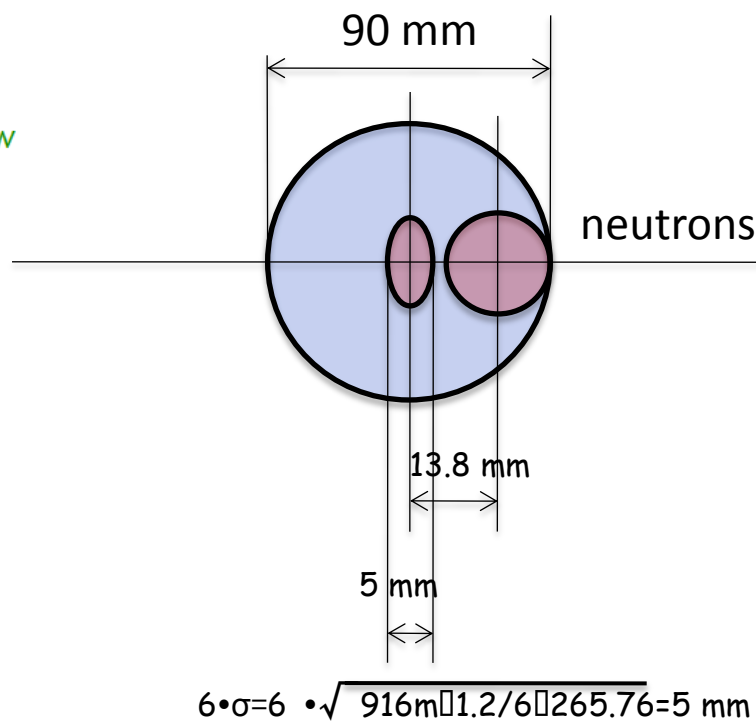
From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012





From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012

Hadron Aperture Q₂

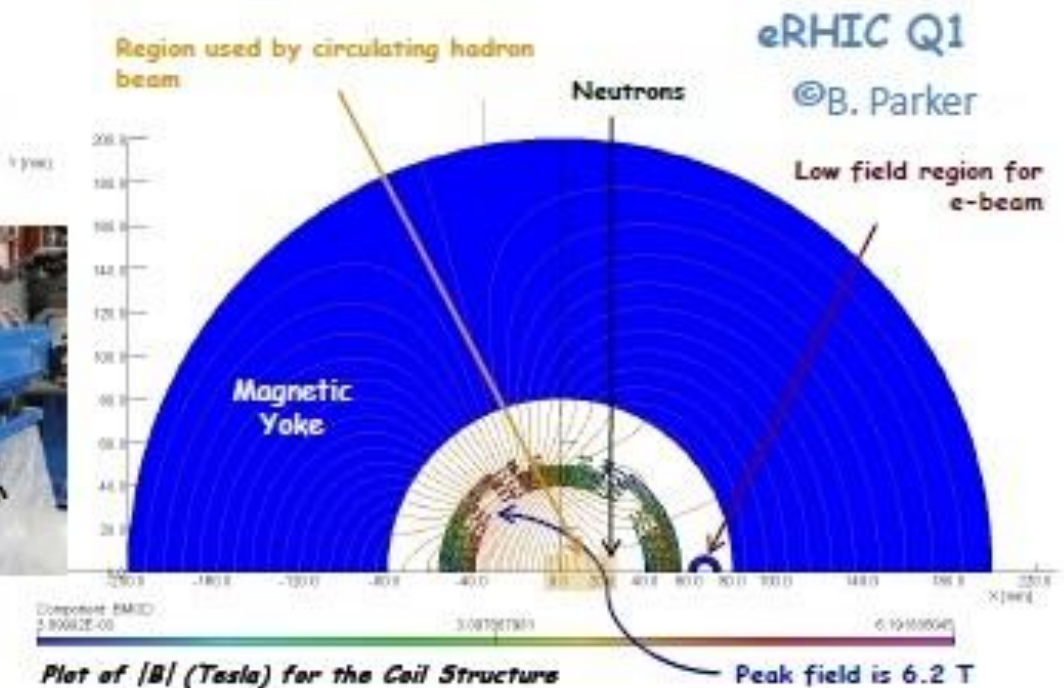


Lattice Optics Name =
IR Location (Right/Left) = Q2
Magnetic Length (m) = left
Gradient (T/m) = 1.5157 m
Residual Field at e-Beam axis (Gauss) = 200 T/m
Hadron Beam Clear Bore Diameter (mm) = 1 G
Electron Beam Clear Bore Diameter (mm) = 90 mm
E-beam Center Offset Front (mm) = 18 mm
E-Beam Center Offset Back (mm) = 82.3 mm
103.4675 mm

Name & Date filled Out _____

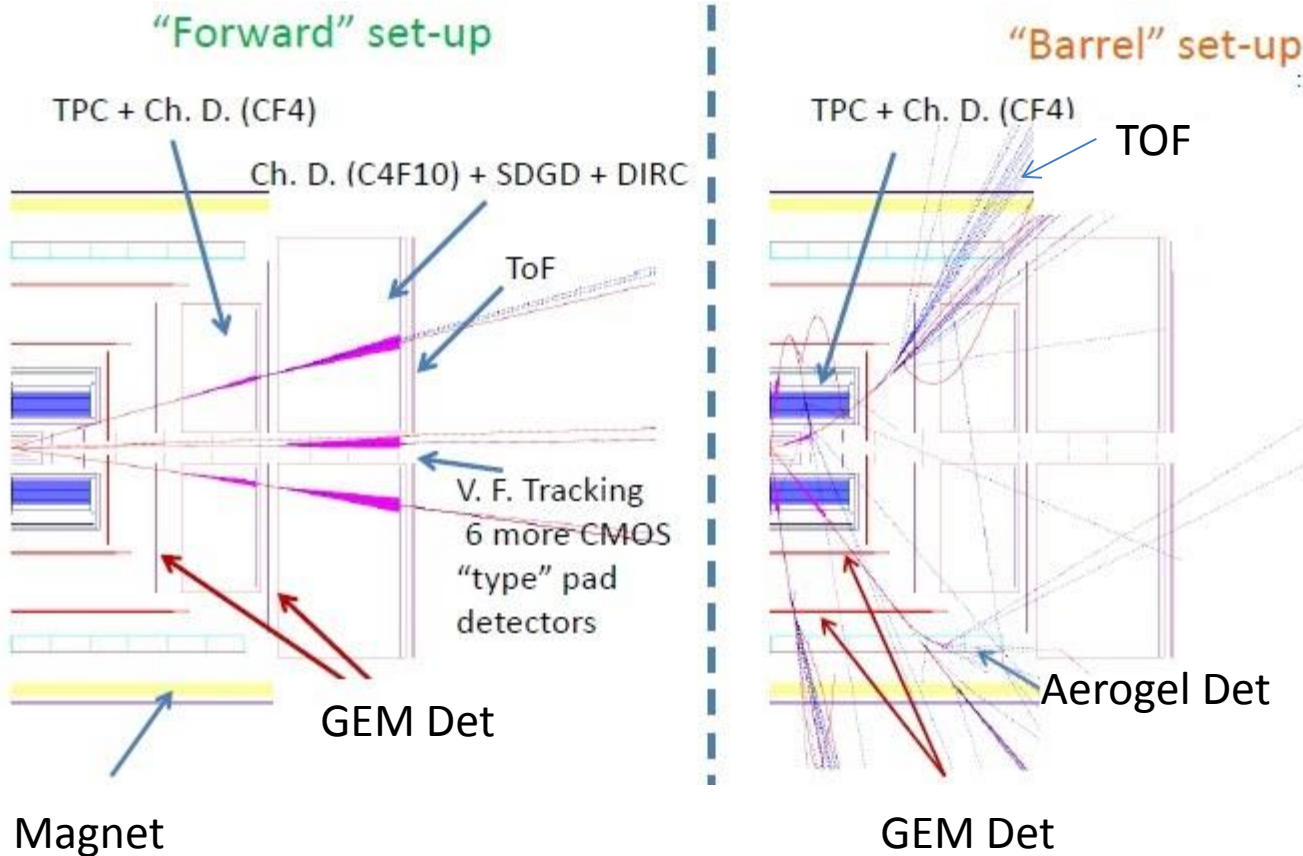
The special IR magnet

- Large aperture for passage of neutrons and gammas, circulating beam and off-momentum charged particle.
- Based on Nb₃Sn magnet technology developed for LHC IR upgrade



From: Y.Hao on behalf of eRHIC design team
2012 RHIC & AGS Annual User's Meeting

Tracking System



Calorimeters

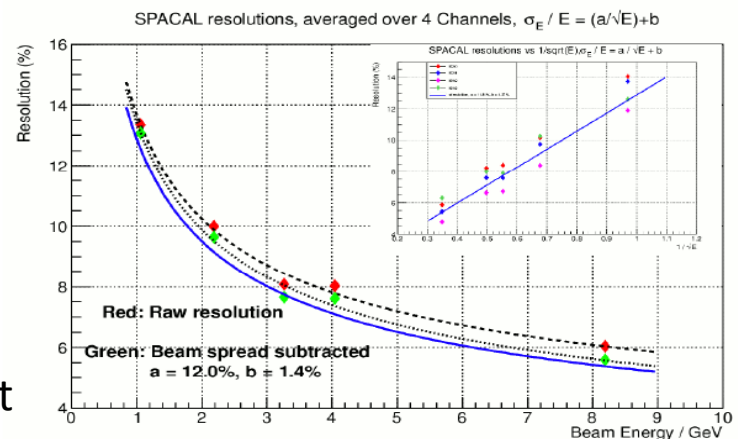
New technologies under consideration:

STAR Forward Calorimeter: Tungsten Powder/Epoxy/SciFi

O. Tsai, H. Huang (UCLA)



Fermilab Test Beam result



Pure tungsten metal sheet ($\rho \sim 19.3 \text{ g/cm}^3$)

Thickness: 2x1.0 mm

Tungsten powder epoxy

($\rho \sim 10\text{-}11 \text{ g/cm}^3$)

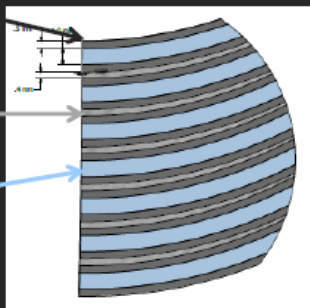
0.08-0.2 mm

Scintillating fibers

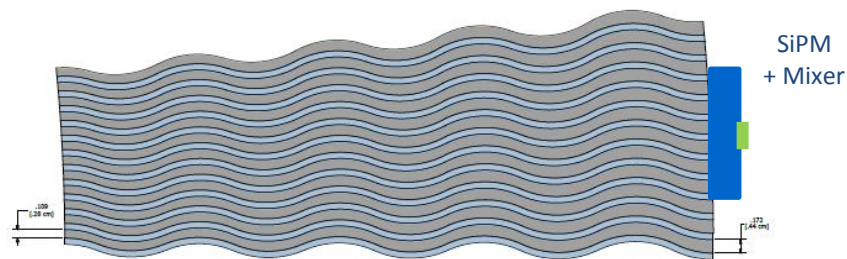
1.0 mm

$X_0 = 5.3 \text{ mm}$

$R_M = 15.4 \text{ mm}$



Tungsten-Scintillating Fiber
"Optical Accordion" EM Calorimeter

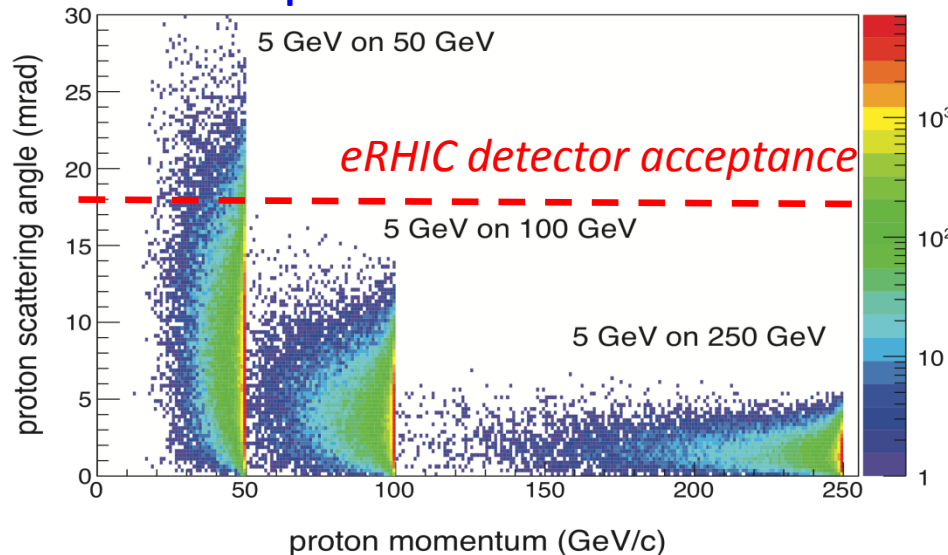
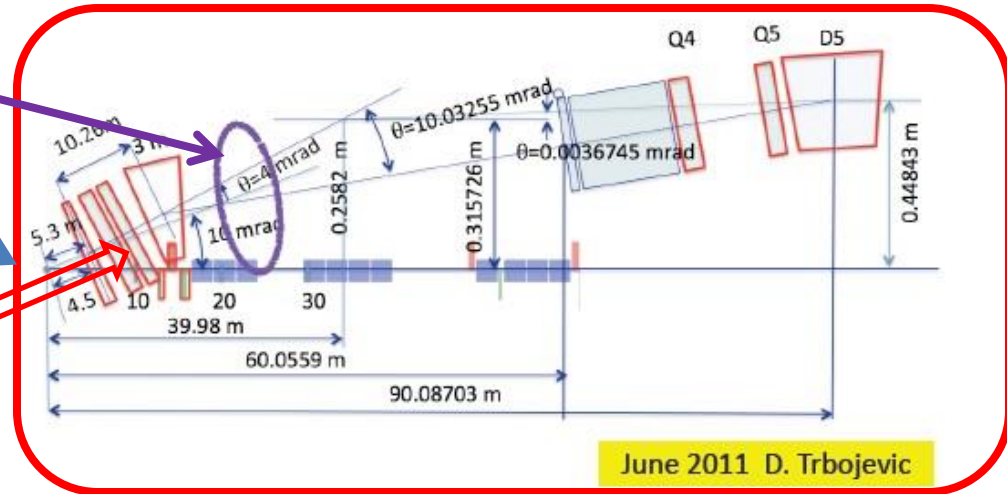


Roman Pots Studies

Roman Pots station
(20 – 22 m from IP)
Interaction Point

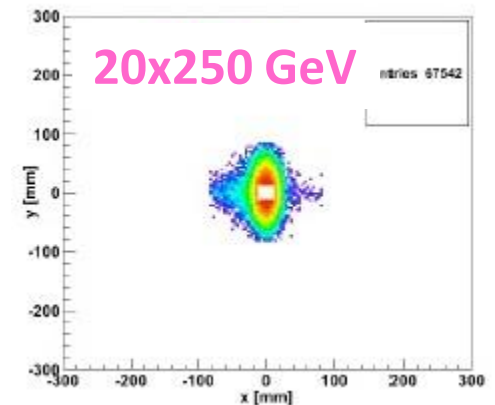
Hadron Beam Direction

leading protons are never in the main
detector acceptance at EIC



Main
detector

Roman
Pots



eRHIC Collider parameters (still valid?)

	e	p	² ₃ He	⁷⁹ ₁₉₇ Au	⁹² ₂₃₈ U
Energy, GeV	10	250	167	100	100
CM energy, GeV		100	82	63	63
Number of bunches/distance between bunches	107 nsec	111	111	111	111
Bunch intensity (nucleons)	$0.24 \cdot 10^{11}$	$4 \cdot 10^{11}$	$6 \cdot 10^{11}$	$6 \cdot 10^{11}$	$6.3 \cdot 10^{11}$
Bunch charge, nC	5.8	64	60	39	40
Beam current, A	0.05	0.556	0.556	0.335	0.338
Normalized emittance of hadrons 95%, mm mrad		1.2	1.2	1.2	1.2
Normalized emittance of electrons, rms, mm mrad		16	24	40	40
Polarization, %	80	70	70	none	none
RMS bunch length, cm	0.2	5	5	5	5
β^* , cm	5	5	5	5	5
Luminosity per nucleon, cm ⁻² s ⁻¹		2.7×10^{34}	2.7×10^{34}	1.6×10^{34}	1.7×10^{34}

Roman Pots Studies

Accepted in "Roman Pot" (example) at s=20m

